Mars Science Laboratory (MSL) Focused Technology Task

Exhibit I

Parachute Decelerator System (PDS)

Performance Specifications

October 11, 2003

Jet Propulsion Laboratory
California Institute of Technology

CHANGE LOG

DATE	SECTIONS CHANGED	REASON FOR CHANGE	REVISION

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1.0 SCOPE

1.1 GENERAL

This specification establishes the performance, design, fabrication, and test requirements for an aerodynamically deployable decelerator system to be used in the Mars Science Laboratory (MSL) Subsonic Parachute Focused Technology Task. The principal elements of the system are a main parachute and a drogue parachute. Hereinafter the total system is referred to as the Parachute Decelerator Subsystem (PDS).

1.2 BACKGROUND/PHILOSOPHY

The MSL mission will land an approximately 1000kg rover on Mars for planetary exploration. The parachute systems developed for past Mars missions (Viking/Pathfinder/Mars Exploration Rover) do not have sufficient drag area to meet the trajectory needs of the MSL mission. Hence, the project has undertaken the development and testing of a large Ringsail main parachute that will be deployed at subsonic conditions. The focus of this effort will be a series of high altitude drop tests occurring during the fall of 2004.

2.0 DEFINITIONS

2.1 PARACHUTE DECELERATION SUBSYSTEM

The MSL Subsonic Parachute Focused Technology Task is to demonstrate at high altitude in the Earth's atmosphere the deployment and inflation of a large Ringsail main parachute that will be suitable for use at Mars. The contractor will be responsible for delivering the PDS for this test. The PDS is to incorporate the following assemblies:

2.1.1 MAIN PARACHUTE ASSEMBLY

The main parachute assembly is a large Ringsail parachute. In flight at Mars, it decelerates the entry vehicle and establishes a stable vertical trajectory to permit jettisoning the heat shield and deployment of the lander. The purpose of this Focused Technology Task is to demonstrate the deployment, inflation, and flight of this parachute in relevant conditions. Measurements will be made to assess the parachute performance. The parachute consists of the main drag surfaces, suspension lines, riser, a triple-bridle assembly, and a deployment bag. Once the Drop Vehicle / Main Parachute Assembly has descended to the ground, the main parachute will be released from the Drop Vehicle by electrically activated mechanisms.

2.1.2 DROGUE PARACHUTE ASSEMBLY

The drogue parachute assembly is a parachute that will be used to extract the main parachute. During high altitude testing, this parachute will be flown in an fully extracted (i.e., deployed) configuration, directly above the Drop Vehicle. The parachute consists of the main canopy, suspension lines, riser, and a triple-bridle assembly. The drogue parachute accommodates attachment to the balloon release mechanism at its apex. The drogue parachute accommodates the launch vehicle adapter assembly, to be inserted between the single riser and the triple bridle confluence point. The triple bridle connects to the drop vehicle.

2.2 DROP VEHICLE

The Drop Vehicle (DV) is the payload that will be suspended underneath the parachutes. It simulates the lander / aeroshell system for Mars flight. The DV will contain a set of instrumentation to record the deployment and inflation event and measure the inflated performance of the main parachute. The DV will be built by JPL.

3.0 REQUIREMENTS

3.1 GENRAL

The test sequence, during which the PDS functions, is described by the following general sequence:

a. Assembly of components into flight train

b. Launch of balloon and ascent to 32 – 39 km.

c. Release of test article from balloon; inflation of drogue

d. Timed fall to desired test conditions

e. Initiation of drogue / Drop Vehicle separation which begins the test of the performance of the main parachute assembly.

3.2 MAIN PARACHUTE ASSEMBLY

a. A Ringsail-type canopy shall be used. This is to take full advantage of existing data derived from many past NASA and military programs.

b . The Contractor shall determine the structural design, number and material of lines, material of drag surface, seams and joints, method of payload attachment, method of packing, etc.

c. The main parachute shall be attached to the drop vehicle in a remote trigger releasable fashion to be developed by JPL with contractor inputs during the performance of the contract.

3.2.1 DESIGN AND CONSTRUCTION (Main)

3.2.1.1 Parachute configuration

The canopy for the main parachute shall be of a Ringsail configuration, or some modification thereof. The goal of this design should be, in order of priority, to provide reliable positive inflation over the range of deploy conditions, maximize drag, and keep the trim angle less than 9 degrees.

3.2.1.2 Parachute size

The main parachute will have a nominal diameter of 33.5 $\pm$ 1 m. After construction, this diameter will be known to $\pm$ 0.1 m.

3.2.1.3 Trailing distance

The skirt of the main parachute will be 39 m behind the interface to the drop vehicle.

3.2.1.4 Interfaces to Drop Vehicle

The main parachute interfaces are shown in the mechianical Interface Control Document and are explained below. They include a volume available for parachute stowage, a triple bridle attachment footprint, and a deployment bag leash.

3.2.1.4.1 Packed Parachute Volume

The parachute, while packed in its deployment bag, will be attached to the parachute stowage plate and fit within the annular volume specified by the Mechanical Interface Control Document (Attachment I).

3.2.1.4.2 Triple bridle attachment

The triple bridle of the main parachute will be attached to the Drop Vehicle at the three locations specific in the MICD. The main parachute must have the capability to be released from the Drop Vehicle after ground impact by electrically activated release mechanisms. The contractor will propose methodologies and hardware to allow this remote release to be implemented.

3.2.1.4.3 Deployment Bag Leash

The deployment bag leash shall attach to the drogue parachute triple bridle confluence point.

3.2.1.5 Factors of Safety

The contractor will propose the appropriate factor of safety, with JPL final approval, to use for the canopy, suspension lines, riser, and bridle with the understanding that there will likely be no ground test of the main parachute subsystem before the high altitude flights. JPL approval of the factor of safety will be required. Loads information can be derived from the inflation design points in section 3.2.2.1

3.2.1.6 Planetary Protection Compatibility

All items to be incorporated in the PDS shall be compatible with microbial reduction (partial sterilization) by thermal cycling or surface cleaning with isopropyl or ethyl alcohol, and microbial sampling with sterile gauze swabs wet with distilled water. It will not be necessary to perform sterilization with hardware for this test series; however, the design must be such that it could be done. In specific, the complete and packaged PDS must be compatible with dry heat microbial reduction. The baseline process conditions are +125°C at the minimum temperature location within the parachute for five (5) hours after the process temperature is achieved. The minimum temperature may be lowered to no less than +110°C, with the process time increased to 50 hours. Intermediate temperatures require a duration per the formula:

$$t(\text{hours}) = 5 \times 10^{(125-T(°C))/21}$$

3.2.1.7 Reefing option

The main parachute canopy shall be designed and constructed so that an optional reefing system can be installed. This reefing system should be designed to assist orderly inflation while minimizing increases in total inflation time. The canopy shall be flyable with or without the reefing system. The reefing system should be able to be installed or removed at the field test site.

3.2.2 FUNCTIONAL REQUIREMENTS (Main)

To achieve the required test profile, the drop vehicle with PDS, will be lifted to an altitude of between 32 and 39 km in the Earth’s atmosphere by a high altitude scientific balloon. Upon command from the ground, the system will be separated from the balloon and start to free-fall. The drogue parachute, fully extended, will inflate and the vehicle will accelerate to test conditions in a given number of seconds. After a timer on-board the Drop Vehicle has expired, pyro-release devices will be actuated allowing the drogue to extract the main parachute. Once the drogue parachute has extracted the main parachute, the drogue parachute shall separate from the main parachute. After stable inflation, the Drop Vehicle/ Main Parachute Assembly will descend to the ground. During the free-fall, inflation, and descent, a number of instruments and sensors on board the Drop Vehicle will record and telemeter data. After ground impact, the main parachute will be released from the Drop Vehicle by radio command. The components and data will then be collected for analysis.

3.2.2.1 Inflation design points

Table 1 presents the expected range of conditions at the initiation of main parachute deployment.

Table 1. Parachute Decelerator System Structural Design Conditions

	Nominal	**Minimum**	**Maximum**
Dynamic Pressure, N/m^2	100	60	220
Mach Number	.75	.3	.8
Earth Altitude, km, MSL	36	25	42
Velocity, m/s	170	85	250
Angle of Attack, degrees	+/- 15	0	+/- 25

Five sample cases are listed in Table 2. These cases provide deployment conditions with parameters that are consistent and representative of realistic Earth test conditions. Note, however, that the design must be such that it is functional at any point occurring within the ranges specified in Table 1.

Table 2. Representative Conditions at Deployment

Dynamic Pressure	**Mach Number**	**Velocity**	**Density**
(N/m^2)		**(m/s)**	**(kg/m^3)**
60	0.3	88	0.015
220	0.8	250	0.007
84	0.8	250	0.0027
150	0.5	155	0.012
105	0.65	210	0.0047

3.2.2.2 Deployment

The main parachute shall be deployed in a controlled manner, so as to prevent parachute malfunction. The deployment system shall cause no damage to the parachute. Damage is defined as any event that will reduce the drag coefficient by more than 5% or induce an increase of trim angle of attack of more than 1 degree. Contact between any deployment components ejected from the entry vehicle during main parachute deployment and the main parachute after deployment shall not cause damage to the parachute or interfere with its operation.

3.2.2.2 Suspended mass

The mass suspended underneath the main parachute shall be 860 $\pm$ 100 kg. Drop Vehicle inertia data will be provided by JPL at a later time.

3.3 DROGUE PARACHUTE ASSEMBLY

a. The drogue parachute primary function is the extraction of the main parachute. During balloon ascent, the drogue parachute is fully extended. Upon initiation of the test, the drogue parachute / Drop Vehicle is released from the balloon, allowing the drogue to inflate. After a set time, pyro release mechanism will fire allowing the drogue to extract the main parachute. The interface of the drogue onto the Drop Vehicle is specified in Section 3.3.1.4. The interface to the balloon release mechanism is specified in Section 3.3.1.5.

b. The Contractor shall determine the configuration, structural design, canopy size, number and material of lines, material of drag surface, seams and joints, method of payload attachment, method of packing, etc. Note that the contractor is free to choose the configuration of the drogue parachute.

3.3.1 DESIGN AND CONSTRUCTION (Drogue)

3.3.1.1 Parachute configuration

The contractor shall choose the drogue parachute configuration such that it will meet the specifications outlined in section 3.3.

3.3.1.2 Parachute size

The drag area (C_dA) of the drogue parachute, when fully inflated under subsonic conditions, shall be 21 $\pm$ 2 m^2. This requirement can be demonstrated analysis or analysis validated by test.

3.3.1.3 Trailing Distance

The suspension line and riser assembly will be designed such that the skirt of the canopy will be 39 $\pm$ 1 m from the drop vehicle interface. The single riser length must be at least 20 m.

3.3.1.4 Interfaces

The drogue parachute accommodates attachment to the balloon release mechanism at its apex. The drogue parachute accommodates the launch vehicle adaptor assembly, to be inserted between the single riser and the triple bridle confluence point. The triple bridle connects to the drop vehicle.

3.3.1.4.1 Interface to Launch Vehicle Adaptor

The connection between the drogue single riser and the drogue triple bridle shall be a link. This link shall permit the insertion of the launch vehicle adaptor assembly between the riser and triple bridle.

3.3.1.4.2 Interface to Drop Vehicle

The triple bridle interfaces to the drop vehicle at the three points shown in the ICD. These attachments are electrically comandable release mechanisms. The contractor should propose suitable mechanisms for this application similar to those used for the main parachute attachment
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3.3.1.4.3 Interface to Balloon Release Mechanism

The apex of the drogue parachute will be interfaced with a dowel pin of diameter to be determined. After release from the balloon, there will be a 1.5 kg block of aluminum which will stay attached to the apex of the drogure parachute.

3.3.1.5 Factors of Safety

The contractor will propose the appropriate factor of safety to use for the canopy, suspension lines, riser, and bridle with the understanding that there will likely be no ground test of the drogue parachute subsystem before the high altitude flights. JPL will approve the factor of safety selection.

3.3.1.6 Planetary Protection Compatibility

Unlike the main parachute, there will be no requirement to be compatible with sterilization procedures for the drogue parachute.

3.3.1.7 Mass

The mass of the drogue parachute assembly will be less than 12 kg, in order to minimize the probability of recontact between the drogue parachute and the main parachute. In order to exceed this limit, contractor will have to request a waiver from JPL.

3.3.2 FUNCTIONAL REQUIREMENTS (Drogue)

3.3.2.1 Inflation and operating conditions

Because the drogue is flown in a fully extracted state, inflation will begin as soon as the payload in released from the balloon. Inflation must be reliable starting for essentially zero velocity at altitudes between 32 and 42 km. The drogue must operate in conditions up to the range listed in Table 1.

3.3.2.2 Suspended mass

The mass suspended beneath the drogue will be 920 ± 100 kg. A short time after inflation, the drogue will extract the main parachute, and from this point forward the suspended mass will be less than 100 kg.

3.3.2.3 Drogue Static Load Pull-Test

The drogue will be subject to a static load pull test, in which the apex with be held and the triple bridle will be pulled with a load of 40500 N. The drogue will pass this test without mechanical degradation.

3.3.2.4 Stability

During descent, the trim angle of the drogue / Drop Vehicle combination will be less than 15 degrees.

3.4 COMMON REQUIREMENTS

3.4.1 LIFE AND ENVIRONMENTS

The operating environment bounds are described in Table 1 of section 3.2.2.1.

3.4.1.1 Useful Life

The system shall operate to the requirements of this specification at the points and durations indicated in the life and environmental requirements defined below. In addition, adequate reserves of any depletion or wear out elements shall be provided so that the life requirements are met after acceptance by JPL.

3 4.1.2 Transportation, Storage, and Handling

The system shall perform as specified herein for 36 months after delivery to JPL while stored and exposed to the following environments and ranges. The system shall be packaged for shipment and storage unless otherwise specified.

3.4.1.3 Temperature, Pressure and Humidity Environment

The PDS shall be designed to operate in or tolerate, which ever is applicable, the following ground environments:

Controlled Environment (operating):
Ambient Temperature: -40°C to 70°C

Maximum Rate of Temperature Change: 5°C/hr
Relative Humidity: 30% to 70%

Ground Pressure Environment
The PDS ground handling and pressure environment shall be restricted between $7x10^4 N/m^2$ (520 Torr) to $1 x 10^5 N/m^2$ (760 Torr).

Storage and Transportation Environment (non-operating):
Ambient Temperature: 5°C to 50°C
Maximum Rate of Temperature Change: 15°C/hr
Relative Humidity: 0% to 75%

Uncontrolled Environment (non-operating):
Ambient Temperature: -40°C to 70°C
Maximum Rate of Temperature Change: 15°C/hr
Relative Humidity: 0% to 100%

3.4.1.4 Quasi Steady Accelerations

The PDS shall be designed to meet functional requirements after exposure to a 5g balloon launch environment and a 10g balloon release environment.

3.4.1.5 Pyrotechnic Shock

The PDS shall be designed to withstand the pyrotechnic shock spectra shown in Table 4. The PDS shall survive 3 shocks in any direction.

Table 4. Assembly Pyrotechnic Shock Requirements

Zone	Frequency, Hz	QUAL, PF Peak SRS Response (Q=10)
Parachute Assembly	100 100 - 1,600 1,600 - 10,000	80 g + 10.0 dB / Oct. 8,000 g

1g = standard acceleration due to gravity = $9.81 m/s^2$
One shock for PF in each of three orthogonal axes. No test for acceptance.

3.4.1.6 Pressure Range

The PDS shall be designed to operate and/or survive, as required, over all ground ops/mission pressure regimes as shown below. Additionally assemblies required to operate during vehicle ascent and descent phases shall be designed to operate at all intermediate pressure regimes.

Pressure Ranges for all Mission Phases

Mission Phase	Pressure	Explanation

Ground operations	101.3 kPa	sea level
Earth test	0.15 to 0.2 kPa	High Altitude, 42 km

3.4.2 WORKMANSHIP

Workmanship shall be of a uniformly high quality. All aspects of material and construction shall be visually examined and free from defect. Non-conformance shall be reason for rejection. All stitching shall conform to Fed-Std-751.

3.4.3 IDENTICALITY & INTERCHANGIBILITY

The PDS flight-type hardware shall be designed and fabricated to be identical (from article to article) within the requirements of this specification to ensure that the qualification testing results will establish the flight qualifications of each flight type article. Parachute design and fabrication procedures shall be such as to maintain finished dimensions consistent from item to item. Parachute packing procedures, once determined, shall be documented and followed for all test articles.

Assemblies, components, devices and parts shall be fully interchangeable both physically and functionally.

3.4.4 SAFETY

3.4.4.1 Design

The PDS shall be designed so that during assembly, test and when stored, transported or operated in accordance with applicable procedures, it will not cause damage to itself or other equipment or cause injury to or be detrimental to the health or safety of personnel. Conspicuous precautionary markings shall be provided as necessary to warn personnel of hazardous conditions and precautions to be observed to assure the safety of personnel and equipment. Transport and storage of the PDS shall comply with all local, state, and federal safety regulations.

3.4.4.2 Hazardous and Flammable Materials

The materials utilized in the PDS, when subjected to specified environments and operation conditions, shall be selected to minimize the liberation of fumes, vapors, gases, or dust. Those materials shall also be selected to preclude cadmium, and flammable or explosive atmospheres. The use of flammable materials shall be avoided where possible. JPL may approve the use of such materials where such total usage of flammable materials is greater than 0.45 kg (1 lb) or 30 linear cm (12 inches). All materials used to contain hazardous materials shall be shown to be compatible with these materials.

3.4.5 PARTS, MATERIALS, AND PROCESSES

Flight materials shall not degrade in performance so as to adversely affect the successful operation of the PDS in the ground and flight environments specified in Section 3.2.2 herein. Whenever possible, all materials used in the manufacture of the PDS deliverable hardware shall be procured from the same lot to ensure material consistency.

3.4.5.1 Part Selection and Control

A list of parts and materials and processes data used for the PDS and all of its components shall be provided to the JPL Contract Technical Manager for JPL approval.

3 4.5.2 Standard Materials Utilization

Standard and off-the-shelf materials and components shall be used wherever feasible to meet design requirements.

3.4.5.3 Non-Standard Materials Utilization

Non-standard or special-purpose materials and components may be used where necessary to meet design requirements. However, materials and/or processes not previously qualified for which no specification exists, must be qualified per the demonstration requirements of Section 4.0 for use on the PDS. Mechanical properties for materials used in structural design shall be subject to JPL approval.

3.4.5.4 Solvents

Metallic materials susceptible to stress corrosion from halogenated or chlorinated solvents shall be cleaned and processed utilizing JPL approved solvents and processes.

3.4.5.5 Fasteners

Fasteners shall be metric except for those used in interfaces with existing components possessing non-metric bolt patterns. The JPL fastener specialist shall approve all fasteners. All fasteners shall have application appropriate locking devices.

3.4.5.6 Ground Handling and Transportation

The PDS shall include any special features deemed necessary to facilitate ground handling and transportation. The shipping containers shall provide sufficient handling features that will protect the flight and flight spare units during normal ground transportation; e.g., forklift, truck, pallet jack, crane, etc. Special handling instructions shall be clearly identified both inside and outside of the shipping container.

3.4.5.7 Metric Design Convention and Standard

All hardware and associated documentation generated for the PDS shall use metric units per the standards set forth by the International System of Units (SI). This requirement does not apply to pre-existing hardware or documentation utilized in the PDS design.

3.4.6 CLEANLINESS

3.4.6.1 Cleanliness control

The system, its components, and devices shall be assembled, packed, and tested in areas which meet the cleanliness requirements appropriate for the particular activity. The level of assembly at which cleanliness control is imposed shall be established by the Contractor and approved by JPL. Particulates generated by fabric cutting and sewing operations shall not be considered contamination. However, cleaning schedules for bench tops shall be such as to minimize the build-up of such particulates. Cleaned assemblies shall be packaged in clean double bags for storage and/or shipment.

3.4.6.2 Surfaces

Surfaces of hardware shall be free of all visible contamination, such as fingerprints, skin flakes, hair, particles, corrosion products, metal chips, scale, oil, grease, preservatives, adhesives, and any other foreign matter. Visual inspection shall be accomplished under well-lit conditions. Wipe tests, ultraviolet light inspection, and special lights and mirrors are considered aids to visual inspection that may be employed.

3.4.6.3 Personnel Controls

In general, the manufacture of the parachute assembly, until it is packed in its overpack or container, shall be conducted with personnel controls similar to those for the preparation of food. Specifically all personnel handling the materials and the parachute must clean their hands before each work period and after each break. Hairnets or caps must also be worn.

4.0 QUALITY ASSURANCE AND TEST REQUIREMENTS

4.1 GENERAL

This section describes the requirements for the quality program during design and fabrication and defines required data, conditions, and environments for the developmental, acceptance, and qualification tests. The tests themselves are set forth in Sections 4.2, 4.3, and 4.4.

4.1.1 QUALITY ASSURANCE REQUIREMENTS

A quality assurance program shall be conducted at the Contractor's facilities per the requirements defined in the Contract. Maximum utilization of the Contractor's existing processes, test methods and controls shall be made. The Contractor shall perform inspection of the system.

4.2 DEVELOPMENTAL TESTS

The Contractor shall propose a program of developmental tests for the purposes of generating design data, including specific information required by JPL, and demonstrating compliance with certain functional requirements which depend on material and component characteristics. The proposed program shall include a general description of the proposed test methods, facilities, and an estimate of numbers of test articles required.

4.3 ACCEPTANCE TESTS

Acceptance of hardware by JPL shall be done by inspection and analysis. Delivered hardware will come with drawings, material certifications, and other design documentation to demonstrate compliance with the requirements in Section 3.

4.4 QUALIFICATION TESTS

The qualification tests described in this section will be performed by JPL. Information provided in this section is given so that the contractor understands how JPL will be using the delivered hardware.

4.4.1 GROUND EXTRACTION TESTS

JPL will perform a ground based extraction test of the main parachute that will simulate the velocities (provided in Section 3.2.2.2) of the extraction and bag strip. The main parachute system used in this test will not be flown and hence does not have to meet all the requirements of section 3.2. The contractor is free to propose using either an engineering model or some version of the main parachute such that relevant data can be acquired from the extraction test. The contractor will support these tests, in particular, with help analyzing the results.

4.4.2 HIGH ALTITUDE FLIGHT TESTS

JPL will perform high altitude flight tests with the PDS. The ranges of possible conditions for these tests are given in section 3.2.2.1. The contractor will support these tests, in particular, with integration of the PDS onto the DV and with analysis of the results.

5.0 PREPARATION FOR DELIVERY

5.1 GENERAL

Preparation for delivery shall be in accordance with the requirements specified herein.

5.2 MARKING

The exterior shipping container shall be marked in accordance with NHB 6000.1 (1A) section 1A212.

5.3 NASA CRITICAL ITEM LABEL

NASA labels will be furnished by JPL and shall be attached to the exterior of the shipping container.

5.4 SHIPPING

The method of shipping, type of container, and method of packaging shall be in accordance with NHB 6000.1 (1 A) and section 5.5 herein.

5.5 SPECIAL PACKING INSTRUCTIONS

Each system delivered to JPL shall be packaged in accordance with the following instructions and the Contract. The Contractor shall package the system in accordance with approved plans and procedures.

a. The system shall be packed in a puncture-proof box or crate that protects against the effects of shock, vibration, humidity, salt fog, and sand and dust.

5.6 STORAGE OF FLIGHT SYSTEMS

For flight article systems fabricated and stored in excess of seven days before final packing and flight acceptance testing, the articles shall be stored and preserved in accordance with a procedure furnished by the Contractor and approved by JPL. Material and seam/joint coupons shall be stored with critical textile components and/or assemblies in order that possible degradations can be checked before packing and assembly of the systems for delivery.

6.0 NOTES

6.1 ABBREVIATIONS

A	Reference area of parachute or forebody
Cd	Drag Coefficient
DOF	Degree(s) of Freedom
F.S.	Factor of Safety
g	Earth Acceleration Unless Otherwise Specified

Hz	Hertz
JPL	Jet Propulsion Laboratory
m	Mass
MSL	Mars Science Lander
NASA	National Aeronautics and Space Administration
NSI -	NASA Standard Initiator
PDS	Parachute Deceleration Subsystem
q	Dynamic Pressure
RMS	Root Mean Square
RPM	Revolutions Per Minute
TBD	To Be Determined, by JPL or Contractor
TBS	To Be Supplied, by JPL or Contractor

6.2 DEVIATIONS

Deviations to this specification shall be allowed only by written authorization from JPL followed by a revision to this specification.

7.0 ATTACHMENTS

Attachment 1: Interface Control Document